# Comment on "New Limits on Intrinsic Charm in the Nucleon from Global Analysis of Parton Distributions"

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A Comment on the Letter by P. Jimenez-Delgado, T. J. Hobbs, J. T. Londergan, and W. Melnitchouk, Phys. Rev. Lett. **114**, 082002 (2015).

Intrinsic heavy quarks in hadrons emerge from the non-perturbative structure of a hadron bound state [1] and are a rigorous prediction of QCD [2, 3]. Lattice QCD calculations indicate significant intrinsic charm and strangeness probabilities [4, 5]. Since the light-front momentum distribution of the Fock states is maximal at equal rapidity, intrinsic heavy quarks carry significant fractions of the hadron momentum. The presence of Fock states with intrinsic strange, charm, or bottom quarks in hadrons lead to an array of novel physics phenomena [6–8]. Accurate determinations of the heavy-quark distributions in the proton are needed to interpret Tevatron and LHC measurements as probes of physics beyond the Standard Model [9, 10]. Determinations [9, 11, 12] of the momentum fraction carried by intrinsic charm quarks in the proton typically limit $\langle x \rangle_{\mathrm{IC}} \sim \mathcal{O}(1\%)$ at 90% CL, consistent with the EMC analysis of their charm structure function data [13] and the large rate for high-$p_T$ $\bar{p}p \to c\gamma X$ reactions at the Tevatron [14]; however, a precise determination of $\langle x \rangle_{\mathrm{IC}}$ has proven elusive.

The recent letter by P. Jimenez-Delgado et al. (JDHLM) [15] reports $\langle x \rangle_{\mathrm{IC}} = (0.15 \pm 0.09)\%$. The authors include low-energy data from the $ed\,(p) \to e'X$ SLAC experiment [16] in their global fit. They find that this data set places strong constraints on intrinsic charm, although, by their count, only 157 of 1021 data points have $W^2$ in excess of the charm hadronic threshold: $W_{\mathrm{th}}^2 \approx 16\,\mathrm{GeV}^2$. The SLAC measurements of $ed\,(p) \to e'X$ have an overall normalization (systematic) error of $\pm 1.7\,(2.1)\%$, and a relative normalization error of typically $\pm 1.1\%$ [16]. The SLAC data points in the germane regime of $W^2 \gtrsim 16\,\mathrm{GeV}^2$, $x > 0.1$ have even larger statistical uncertainties.

It is clearly challenging to identify the contribution from charm quarks to the inclusive structure function if only the scattered electron is detected. In addition to the valence and sea-quark distributions, there are other contributions to the inclusive cross section which need to be determined to high accuracy in order to discern the intrinsic charm component at the level claimed by JDHLM; this includes higher-twist corrections at high $x$, the strange and bottom quark contributions, as well as the accurate implementation of the suppression of charm production at threshold and nuclear target effects. Their analysis depends on uncertain parameters and theory assumptions. For example, JDHLM model higher-twist effects as an isospin-independent, phenomenological multiplicative factor on top of a leading-twist structure function with target-mass corrections [17]. Their higher-twist model does not include enhancements at $x \sim 1$ resulting from hard subprocesses such as $e[qq] \to e'qq$ where multiple quarks interact [18, 19]. Such processes depend strongly on the diquark charges, making them quark flavor (isospin) sensitive, and they contribute in the same large $x$ domain as the charm signal. In addition, the target mass-corrected structure functions used by JDHLM remain nonzero as $x \to 1$ [17] which is problematic, and they neglect intrinsic strange and beauty quark contributions [7, 20].

JDHLM assess their PDF errors using a tolerance criteria of $\Delta\chi^2 = 1$ at $1\sigma$; however, the actual value of $\Delta\chi^2$ depends on the number of parameters to be simultaneously determined in the fit — their assessment of a single parameter error requires that the other parameters be fixed at their values at the global $\chi^2$ minimum [21]. JDHLM report $\langle x \rangle_{\mathrm{IC}} = (0.15 \pm 0.09)\%$ [15] corresponding to $\Delta\chi^2 = 1$ at $1\sigma$ (68% CL) and also $\langle x \rangle_{\mathrm{IC}} \lesssim 0.5\%$ at $4\sigma$. In order to set a $4\sigma$ limit, all of the other parameters must be varied so as to yield a minimum $\chi^2$ as the parameter of interest is changed [22–25]. We note Refs. [26, 27], e.g., contain 25 PDF parameters in leading twist, and Ref. [27] contains 12 more higher twist parameters. Since one would expect nontrivial correlations and near degeneracies in a many-parameter fit, the apparent agreement of the $4 \times 1\sigma$ assessment with the $4\sigma$ limit suggests that the other parameters were not properly varied as $\langle x \rangle_{\mathrm{IC}}$ was changed, making the reported limit too severe.

It is clear that the SLAC single-arm measurements cannot unambiguously identify an intrinsic charm contribution to the nucleon structure function even at the 1% level because of statistical and systematic uncertainties, both experimental and theoretical. JDHLM have excluded the EMC measurements of the charm structure function [13], citing a "goodness of fit" criterion. However, statistical criteria alone cannot exclude data sets. The fit to the EMC iron target data would be improved by including the QCD nuclear effects described in Refs. [28, 29].

In summary, JDHLM claim that the momentum fraction carried by intrinsic charm quarks in the proton is $\langle x \rangle_{\mathrm{IC}} = (0.15 \pm 0.09)\%$; we do not find this conclusion warranted.

[1] S. J. Brodsky, P. Hoyer, C. Peterson, and N. Sakai, Phys. Lett. B **93**, 451 (1980); S. J. Brodsky, C. Peterson, and N. Sakai, Phys. Rev. D **23**, 2745 (1981).

[2] S. J. Brodsky, J. C. Collins, S. D. Ellis, J. F. Gunion, and A. H. Mueller, in *Proceedings of the 1984 Summer Study on the SSC, Snowmass, CO, June 23 - July 13, 1984*, edited by R. Donaldson and J. G. Morfin (AIP, New York, 1985).

[3] M. Franz, M. V. Polyakov, and K. Goeke, Phys. Rev. D **62**, 074024 (2000) [hep-ph/0002240].

[4] W. Freeman and D. Toussaint, Phys. Rev. D **88**, 054503 (2013) [arXiv:1204.3866 [hep-lat]].

[5] M. Gong *et al.* [XQCD Collaboration], Phys. Rev. D **88**, 014503 (2013) [arXiv:1304.1194 [hep-ph]].

[6] S. J. Brodsky, PoS Hadron **2013**, 013 (2013) [arXiv:1401.5886 [hep-ph]].

[7] F. Lyonnet, A. Kusina, T. Je?o, K. Kova?k, F. Olness, I. Schienbein and J. Y. Yu, arXiv:1504.05156 [hep-ph].

[8] S. J. Brodsky, A. Kusina, F. Lyonnet, I. Schienbein, H. Spiesberger, and R. Vogt, arXiv:1504.06287 [hep-ph].

[9] S. Dulat, T. J. Hou, J. Gao, J. Huston, J. Pumplin, C. Schmidt, D. Stump, and C.-P. Yuan, Phys. Rev. D **89**, 073004 (2014) [arXiv:1309.0025 [hep-ph]].

[10] N. Brambilla, S. Eidelman, P. Foka, S. Gardner, A. S. Kronfeld *et al.*, Eur. Phys. J. C **74**, 2981 (2014) [arXiv:1404.3723 [hep-ph]].

[11] B. W. Harris, J. Smith, and R. Vogt, Nucl. Phys. B **461**, 181 (1996) [hep-ph/9508403].

[12] J. Pumplin, H. L. Lai, and W. K. Tung, Phys. Rev. D **75**, 054029 (2007) [hep-ph/0701220].

[13] J. J. Aubert *et al.* [European Muon Collaboration], Nucl. Phys. B **213**, 31 (1983).

[14] C. Mesropian and D. Bandurin, arXiv:1409.5639 [hep-ex].

[15] P. Jimenez-Delgado, T. J. Hobbs, J. T. Londergan, and W. Melnitchouk, Phys. Rev. Lett. **114**, 082002 (2015) [arXiv:1408.1708 [hep-ph]].

[16] L. W. Whitlow, E. M. Riordan, S. Dasu, S. Rock, and A. Bodek, Phys. Lett. B **282**, 475 (1992).

[17] J. F. Owens, A. Accardi, and W. Melnitchouk, Phys. Rev. D **87**, no. 9, 094012 (2013) [arXiv:1212.1702 [hep-ph]].

[18] E. L. Berger and S. J. Brodsky, Phys. Rev. Lett. **42**, 940 (1979).

[19] S. J. Brodsky, E. L. Berger, and G. P. Lepage, SLAC-PUB-3027, ANL-HEP-8302, C82-10-07.

[20] J. R. Ellis, A. Kotzinian, and D. V. Naumov, Eur. Phys. J. C **25**, 603 (2002) [hep-ph/0204206].

[21] K. A. Olive *et al.* [Particle Data Group Collaboration], Chin. Phys. C **38**, 090001 (2014).

[22] Y. Avni, Astrophys. J. **210**, 642 (1976).

[23] J. Charles *et al.* [CKMfitter Group Collaboration], Eur. Phys. J. C **41**, 1 (2005) [hep-ph/0406184].

[24] J. Liu, R. D. McKeown, and M. J. Ramsey-Musolf, Phys. Rev. C **76**, 025202 (2007) [arXiv:0706.0226 [nucl-ex]].

[25] S. Gardner and B. Plaster, Phys. Rev. C **87**, 065504 (2013) [arXiv:1305.0014 [hep-ph]].

[26] J. Gao, M. Guzzi, J. Huston, H. L. Lai, Z. Li, P. Nadolsky, J. Pumplin, D. Stump, and C.-P. Yuan, Phys. Rev. D **89**, 033009 (2014) [arXiv:1302.6246 [hep-ph]].

[27] P. Jimenez-Delgado and E. Reya, Phys. Rev. D **89**, no. 7, 074049 (2014) [arXiv:1403.1852 [hep-ph]].

[28] D. de Florian, R. Sassot, P. Zurita, and M. Stratmann, Phys. Rev. D **85**, 074028 (2012) [arXiv:1112.6324 [hep-ph]].

[29] D. de Florian, R. Sassot, M. Stratmann, and P. Zurita, arXiv:1204.3797 [hep-ph].